

Appl. No. 10/809,728

Amdt. Dated 12 May 2006

Reply to Office action of 22 March 2006

REMARKS/ARGUMENTS

Reexamination and reconsideration of this application as amended is requested. By this amendment, a substitute specification has been provided, claims 1 and 4 have been amended, and claims 2 and 3 have been cancelled. Claims 1 and 4-5 remain in the application.

OBJECTION TO THE DISCLOSURE

The disclosure has been objected to because page 3 is blank.

After discussions with Examiner Ruthkosky on 12 May 2006, it was agreed that the best way to overcome publication issues would be to submit a substitute specification; therefore, a substitute specification is attached. Page 4 of the original specification now becomes page 3 of the substitute specification, and so on.

Accordingly, it is believed that the objection to the disclosure has been overcome by the amendment and remarks.

REJECTION OF CLAIMS 1, 2, AND 4-5 UNDER 35 U.S.C. §102

Claims 1, 2, and 4-5 have been rejected under 35 U.S.C. 102 as being anticipated by Lussey et al. (US 6,495,069).

The limitations of allowed claim 3, and of intermediate claim 2, have been incorporated into claim 1. Claims 2 and 3 have been cancelled. Claim 4 has been amended to depend from claim 1.

Accordingly, it is believed that the rejection of claims 1, 2, and 4-5 under 35 U.S.C. 102 has been overcome by the amendment and remarks.

ALLOWABLE CLAIMS

Claim 3 has been identified as being allowable.

The limitations of allowed claim 3, and of intermediate claim 2, have been incorporated into claim 1.

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CONCLUSION

The cited reference has been reviewed and is not believed to affect the patentability of the claims as amended.

No amendment made herein was related to the statutory requirements of patentability unless expressly stated; and no amendment made herein was for the purpose of narrowing the scope of any claim, unless Applicant has argued herein that such amendment was made to distinguish over a particular reference or combination of references.


In view of Applicant's amendments and remarks, it is respectfully submitted that Examiner's rejections have been overcome. Accordingly, Applicants respectfully submit that the application, as amended, is now in condition for allowance, and such allowance is therefore earnestly requested. Should the Examiner have any questions or wish to further discuss this application, Applicants request that the Examiner contact the Applicants attorneys at 480-385-5060.

If for some reason Applicants have not requested a sufficient extension and/or have not paid a sufficient fee for this response and/or for the extension necessary to prevent abandonment on this application, please consider this as a request for an extension for the required time period and/or authorization to charge Deposit Account No. 502,091 for any fee which may be due.

Respectfully submitted,

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**FUEL CELL USING NON-LINEAR POSITIVE
TEMPERATURE COEFFICIENT MATERIAL**

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CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of pending U.S. application Serial Number.
09/999,387, filed October 31, 2001, and assigned to Motorola, Inc.

TECHNICAL FIELD

This invention relates in general to fuel cells, and more particularly to a system
10 for controlling hot spots that tend to occur on fuel cell membrane electrode assemblies.

BACKGROUND

In recent years, nearly all electronic devices have been reduced in size and
made lightweight, in particular portable electronic devices. This advancement has
15 been made possible, in part, by the development of new battery chemistries such as
nickel-metal hydride, lithium ion, zinc-air, and lithium polymer, that enable larger
amounts of power to be packaged in a smaller container. These secondary or
rechargeable batteries need to be recharged upon depletion of their electrical capacity.
This is typically performed by connecting the battery to a battery charger that converts
20 alternating current to a low level direct current of 2-12 volts. The charging cycle
typically lasts a minimum of 1-2 hours, and more commonly 4-14 hours. Although the
new batteries are a tremendous advancement over the previous generations of
batteries, they still suffer from the need for sophisticated charging regimens and the
slow charging rates.

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Fuel cells are expected to be the next major source of energy for portable
electronic products. Simply put, fuel cells catalytically convert a hydrogen molecule
to hydrogen ions and electrons, and then extract the electrons through a membrane as
electrical power, while oxidizing the hydrogen ions to H₂O and extracting the
30 byproduct water. The tremendous advantage of fuel cells is the potential ability to
provide significantly larger amounts of power in a small package, as compared to a
battery. Their potential ability to provide long talk-times and standby times in portable
electronic device applications are driving miniaturization of fuel cell technologies.

The polymer electrolyte membrane (PEM) based air-breathing, dead-ended fuel cells are ideally suited for powering portable communication devices. One of the key operating challenges in a small dead-ended fuel cell system is the temperature regulation at different points on the cells. Since these fuel cells do not have forced gas circulation or external membrane water management systems, the distribution of fuel gas and water over the area of the membrane electrode assembly (MEA) of the fuel cell will be non-uniform. This non-uniform distribution has the potential to create significant hot spots which can destroy the MEA and hence the performance of the fuel cells.

In a dead-ended air-breathing hydrogen/air fuel cell, the electrolyte membrane would have a tendency to dehydrate when it is operated at a relatively high current. As the membrane dries, the internal resistance of the cell increases, and the power output of the cell is substantially reduced. Undesirably, this drying out can progressively march across the PEM until the fuel cell fails completely. The increase in internal resistance produces I^2R heating which develops into "hot spots". Though prior art technologies exist to control some sources of hot spots, there is no practical prior art technique that will significantly eliminate the probability of encountering hot spot conditions. In addition, the prior art methods use active systems, that require external components, which are not practical for a portable fuel cell based power source. Most of the prior art methods focus on membrane hydration and water management methods to prevent the creation of hot spots. For example, US patents 5858567, 6156184, and 6207312 teach various techniques for membrane hydration. These methods are based on an approach which attempts to keep the entire electrolyte membrane hydrated at high enough level to survive the highest level of current density without drying out the membrane. In addition, hot spots can be caused by factors other than electrolyte membrane dehydration such as poor distribution of fuel gases. The prior art methods are cumbersome and are not fail-proof; they can fail for a variety of reasons including non-uniformity of membrane material, aging of the materials and localized variations in concentration of fuel gas. In addition, maintaining a high level of hydration to keep the entire electrolyte membrane fully hydrated can cause flooding on the cathode side of the fuel cell. Therefore, a better approach is needed for controlling hot spots in fuel cell systems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of the resistance-temperature relationship for a non-linear positive temperature coefficient material.

FIG. 2 illustrates a fuel cell according to a first embodiment of the present invention.

FIG. 3 is a schematic representation of a fuel cell according to a second embodiment of the present invention.

FIG. 4 is a schematic representation of a fuel cell according to a third embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A method and apparatus for passively controlling creation and growth of hot spots in a fuel cell system is disclosed. A typical fuel cell based power source has many unit fuel cells that are connected to each other in series. Each of the fuel cells has a membrane electrode assembly which consists of an electrolyte layer, a cathode and an anode disposed on either side of the electrolyte layer. The fuel cell also has a gas diffusion layer (GDL) and a current collector on each side of the MEA. The current collector gathers the free electrons produced during the electrochemical reaction. In a dead-ended air-breathing hydrogen/air fuel cell, the electrolyte membrane would have a tendency to dehydrate when it is operated at a relatively high current. As the membrane dries, the internal resistance of the cell increases, increasing I^2R heating which develops into "hot spots". Hot spots can also be caused by poor distribution of fuel gases, high concentration of fuel gas at localized areas, runaway reaction at some areas of the MEA and localized shorting of the cell. One way to avoid progressive degradation from hot spot initiation to a complete failure of the MEA is to electrically isolate the hot area so that very little current is drawn through that area. This will eliminate I^2R heating in that area and allow that area to recover and rehydrate.

Materials that respond to increase in temperature with increased electrical resistance are said to exhibit positive temperature coefficient (PTC) behavior. One class of PTC materials called non-linear positive temperature coefficient (NPTC)

materials, exhibit a unique resistance versus temperature characteristic, maintaining a low resistance over a wide temperature range, then dramatically increasing the resistance (several orders of magnitude) above a specific temperature called the "Curie" or "switching" point. This critical temperature increase can be caused by
5 internal heat due to electrical current flow (I^2R loss) or from external ambient temperature rise. Removing the heat source allows the NPTC material to cool, returning it to its initial base resistance. FIG. 1 schematically shows the non-linear relationship between resistance and temperature for a typical NPTC material. In the figure, first-part 100 of the curve shows the region of low resistance which is the
10 normal operating state of the NPTC material. The "Curie" point 110 and the high-resistance region 120 are also shown in the figure.

The electrical resistivity of NPTC materials along the three principal directions (X, Y, Z) can be custom tailored by appropriate selection of base materials, conductive
15 fillers and dopants. NPTC materials, in sheet form, that have very low electrical resistivity along its thickness direction (Z) and very high electrical resistivity along the other two directions (X and Y) are said to exhibit Z-axis conductivity. The Z-axis conducting NPTC materials used in various embodiments of this invention have a porous structure to allow fuel cell reactants to pass through them. In addition, the
20 porous structure improves the Z-axis conductivity while significantly reducing its X and Y direction conductivity. In different embodiments of the present invention, a layer of porous Z-axis conductive NPTC material is disposed between one or more layers of the fuel cell of the prior art to control the amount of current drawn through different locations on the fuel cell MEA thus controlling the I^2R heating at localized
25 areas of the MEA.

A method of operating a fuel cell, having a membrane electrode assembly, involves selectively limiting the quantity of electrons collected from localized areas of the MEA surface. Selective limiting of the quantity of electrons collected from
30 localized areas of the MEA is realized by a layer of NPTC material located together with the membrane electrode assembly or the current collector of the fuel cell. The Z-axis electrical resistivity of the NPTC material at localized areas on the NPTC material layer changes from a low value to a high value in response to a trigger condition, on

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the MEA side adjacent to the NPTC material layer. A trigger condition is created when one or more of the parameters, indicating the state of local areas of the MEA, cross a threshold value. Some of the parameters that are appropriate trigger initiators are temperature, pH, hydrogen concentration, electrolyte water content, electrolyte
5 thickness, electrolyte ionic conductivity and electrolyte electronic conductivity at local areas of the MEA.

FIG. 2 shows a schematic view of one embodiment of the present invention. The apparatus consists of a single fuel cell unit 200 having a membrane electrode
10 assembly 210 having two opposing major sides. The membrane electrode assembly comprises an electrolyte 220 disposed between and in intimate contact with an anode 230 and a cathode 240. The contact surface between the electrolyte 220, and the electrodes 230, and 240 are coated with noble metal catalysts such as platinum black. A layer of porous, Z-axis conducting NPTC material 250 is disposed on either side of
15 the MEA and in intimate contact with the opposing major surfaces of the MEA. Further, a gas diffusion layer (GDL) 260 is disposed on the surfaces of the NPTC layer that is opposite to the one in contact with the MEA. A current collector layer 270 is disposed on the GDL layer that is opposite to the one in contact with the NPTC layer. During fuel cell operation, the hydrogen molecule dissociates at the electrolyte/catalyst
20 interface into hydrogen ions, H^+ , and electrons, e^- . The hydrogen ions migrate from the anode side to the cathode side through the electrolyte and the electrons flow around the external electrical load to the cathode side. The electrons generated at the electrolyte/catalyst interface migrate through the anode, NPTC and GDL layers and are gathered together by the current collector and channeled to an electrical terminal
25 connected to the external electrical load.

While the fuel cell operates, many different conditions such as poor distribution of fuel gases, high concentration of fuel gas at localized areas, runaway reaction at some areas of the MEA, localized dehydration of the electrolyte, and
30 localized shorting of the cell can cause hot spots. A hot spot caused by any of the conditions manifests itself as rapid, localized heating of the MEA. In an embodiment of the present invention, when any part of the MEA begins to heat up creating a potential condition for hot spot development, the area of NPTC material adjacent to

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the MEA starts to heat up. Through appropriate selection of the NPTC material, the "Curie" point can be tailored to be below the temperature at which hot spots will inhibit the performance of the fuel cell. At this condition, the Z-axis electrical resistivity of the NPTC layer at areas where the temperature is over the "Curie" point will be very high. This significantly reduces the quantity of electrons flowing through that area of the NPTC layer virtually shutting off current flow in those local areas. The reduced current flow results in a substantial reduction in the reaction rate at areas of electrolyte/catalyst interface adjacent to the shut-off NPTC areas, ultimately halting the formation of hot spots and decreasing local surface temperature. Once the temperature of the local areas of the NPTC layer drops below the "Curie" point, electrical resistivity returns to its normal value and the reaction progresses as before. This regulation of current flow through local areas of the NPTC layer is fully reversible, completely passive and self-regulating.

Some of the common classes of NPTC materials that are appropriate for use in various embodiments of the invention are polymer positive temperature coefficient (PPTC) materials, ceramic positive temperature coefficient (CPTC) materials and semiconducting positive temperature coefficient (SPTC) materials. The material selected for a particular embodiment or application will depend on the choice of MEA materials and their construction, the choice of GDL materials and the operating characteristics of the fuel cell. A typical polymer NPTC layer comprises a polymer matrix that is loaded with carbon black particles to make it conductive. As a local area of the PPTC layer begins to heat up, the polymer matrix will expand and the carbon particles will separate increasing the Z-axis resistance of the area. This will cause the area to heat faster and expand more, further raising the resistance. When the temperature of the area reaches the Curie point, the resistance increases dramatically, substantially reducing the current flow through the local area of the PPTC layer. As the local area cools, polymer matrix contracts to its original shape and reconnects the carbon particles thus lowering the resistance of the area to a normal level. The initial resistance, the trip resistance and the Curie point temperature of PPTC materials can be custom tailored for each application. Typical commercial PPTC materials that are appropriate for use in various embodiments of the present invention have an initial Z-axis resistivity of the order of $1E-5$ Ohm-meter which approximately remains constant

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until the Curie point is reached, at which time the resistivity rapidly increases at least by a factor of 10.

Although the first embodiment describes an apparatus that has porous Z-axis
5 conducting NPTC material disposed on both sides of the MEA, other variations can be realized by disposing the NPTC material only on the anode or the cathode side of the MEA. Since the anode side of a hydrogen fuel cell is more prone to developing hot spots, it may be more beneficial to dispose the NPTC material only on the anode side of the MEA. A second embodiment of the present invention that addresses this
10 concern is schematically shown in FIG. 3. The system consists of a single fuel cell unit 300 having a membrane electrode assembly 310 having two opposing major sides. The membrane electrode assembly comprises an electrolyte 320 disposed between and in intimate contact with an anode 330 and a cathode 340. The contact surface between the electrolyte 320, and the electrodes 330, and 340 are coated with noble metal
15 catalysts such as platinum black. A layer of porous, Z-axis conducting NPTC material 350 is disposed on the anode side of the MEA and in intimate contact with the anode surface of the MEA. Further, a GDL 360 is disposed on the surface of the NPTC layer that is opposite to the one in contact with the MEA on the anode side, and on the cathode surface on the cathode side. A current collector layer 370 is disposed on the
20 GDL layer. When any part of the MEA 310 begins to heat up creating a potential condition for hot spot development, the area of NPTC material adjacent to the MEA on the anode side starts to heat up. At this condition, the Z-axis electrical resistivity of the NPTC layer at areas where the temperature is over the "Curie" point will be very high. This significantly reduces the quantity of electrons flowing through that area of
25 the NPTC layer virtually shutting off current flow in those local areas. The reduced current flow results in a substantial reduction in the reaction rate at areas of electrolyte/catalyst interface adjacent to the shut-off NPTC areas, ultimately halting the formation of hot spots and decreasing local surface temperature. Once the temperature of the local areas of the NPTC layer drops below the "Curie" point,
30 electrical resistivity returns to its normal value and the reaction progresses as before.

FIG. 4 shows a schematic view of another embodiment of the present invention. The system consists of a single fuel cell unit 400 having a membrane

electrode assembly 410 having two opposing major sides. The membrane electrode assembly comprises an electrolyte 420 disposed between and in intimate contact with an anode 430 and a cathode 440. The contact surface between the electrolyte and the electrodes are coated with noble metal catalysts such as platinum black. A GDL 460 is
5 disposed on either side of the MEA and in intimate contact with the opposing major surfaces of the MEA. A GDL material exhibiting Z-axis conductivity is used in this embodiment. Further, a layer of porous, Z-axis conducting NPTC material 450 is disposed on the surfaces of the GDL layer that is opposite to the one in contact with the MEA. A current collector layer 470 is disposed on the NPTC layer that is opposite
10 to the one in contact with the GDL layer.

A novel fuel cell design that passively regulates the quantity of electrons collected at different areas of active surface of a fuel cell based on the localized MEA surface condition is disclosed. For example, by interposing a porous, Z-axis
15 conductive NPTC material between one or more layers of the fuel cell membranes and through selection of NPTC materials with appropriate "Curie" point for a given application, significant reduction in hot spot failures can be realized. The novel configuration also maintains the regulation latched until the temperature drops below a threshold, so that "hot spots" are eliminated from the active surface. This approach of
20 using an inherent property of NPTC materials results in a system that passively controls creation and growth of hot spots in a fuel cell while overcoming the disadvantages of the prior art methods and devices of this general type.

While the preferred embodiments of the invention have been illustrated and
25 described, it will be clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the appended claims.

30 What is claimed is:

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CLAIMS

1. A method of operating a fuel cell, comprising the steps of:
activating a membrane electrode assembly by supplying reactants to the
5 membrane electrode assembly; and
selectively limiting amount of electrons collected from localized areas of
the membrane electrode assembly surface.
2. The method of claim 1, wherein the step of selectively limiting comprises
10 the step of utilizing a porous, Z-axis electrically conductive, non-linear positive
temperature coefficient material located together with the membrane electrode
assembly to selectively limit the amount of electrons collected from localized
areas of the membrane electrode assembly.
3. The method of claim 2, wherein the step of utilizing further comprises the
15 step of disposing a porous, Z-axis electrically conductive, non-linear positive
temperature coefficient material on and in intimate contact with at least one of
the sides of the membrane electrode assembly.
4. The method of claim 2, wherein the Z-axis electrical resistivity at
20 localized areas of the non-linear positive temperature coefficient material
changes from a first value to a second value in response to a trigger condition
at areas of the membrane electrode assembly adjacent to the localized areas of
the non-linear positive temperature coefficient material.
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5. The method of claim 4, wherein the trigger condition is created in
response to a combination of one or more elements selected from the group
consisting of temperature, pH, hydrogen concentration, electrolyte water
content, electrolyte thickness, electrolyte ionic conductivity and electrolyte
30 electronic conductivity of the membrane electrode assembly adjacent to the
non-linear positive temperature coefficient material layer, crossing a threshold
value.

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**FUEL CELL USING NON-LINEAR POSITIVE
TEMPERATURE COEFFICIENT MATERIAL**

ABSTRACT OF THE DISCLOSURE

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A fuel cell (200) includes a membrane electrode assembly (210) located together with a layer of porous, z-axis electrically conductive, non-linear positive temperature coefficient (NPTC) material (250). The NPTC material (250) operates to selectively limit the amount of electrons collected from localized areas of the

10 membrane electrode assembly (210) in order to reduce hot spots.